FEMTOSECOND ULTRAVIOLET LASER MODIFICATION OF GALLIUM NITRIDE THIN-FILM COATINGS

Paulius Zakarauskas[1], Dominyka Stonytė[1], Arūnas Kadys[2], Darius Gailevičius[1], Domas Paipulas[1]

[1]Laser Research Center, Faculty of Physics, Vilnius University, Sauletekio av. 10, LT-10223 Vilnius, Lithuania
[2]Center for Physical Sciences and Technology, Saulėtekio av. 3, LT-10257 Vilnius, Lithuania
paulius.zakarauskass@gmail.com

Gallium nitride has recently stood out as a material that has a lot of useful properties for electronic and optoelectronic appliances, such as wide band-gap (3,4 eV), high heat capacity, thermal conductivity, break-down voltage, electron mobility and high quantum efficiencies [1]. These properties make gallium nitride a valuable material in developing light emitting diodes (LEDs) [2], field effect transistors (FETs) [3], high-temperature devices [4] and many others. To manufacture these devices from gallium nitride a high-quality processing is needed.

Recent advancements in the development of ultrashort pulse lasers allow high-quality micro-processing of materials. It is well known that the use of ultrashort laser pulses, compared to longer ones, give more control in the ablation process and also increase the resolution of micro-processing, due to reduction of heat-affected zones (HAZ) because the temporal length of the pulse is lower than the length of thermal diffusion. Most approaches use femtosecond lasers with wavelengths longer than ultraviolet [5]. However, shorter wavelengths in UV spectral range could benefit in decreasing heat-affected zones due to linear (one photon) absorption and smaller focus point, because it is directionally proportional to the wavelength. This technique was tested with the use of longer nanosecond pulses of excimer UV lasers [6]. Nevertheless, laser processing using UV femtosecond laser pulses has seldom been studied.

In this study we directly ablate thin-film undoped gallium nitride using femtosecond ultraviolet laser pulses [257 nm, 100 kHz, 240 fs] with different pulse energy and pulse overlapping. The topographies of ablated regions were measured with a profilometer (repeatability σ_{n-1} = 12 nm). The ablated structures were characterized using three variables: ablation depth, ablation efficiency and average modified surface roughness S_a, calculated according to ISO 25178-3:2012. Our results indicate that the use of femtosecond UV laser pulses enable high resolution and high-quality ablation with minimal heat affected zones (HAZ) while processing wide band-gap materials such as gallium nitride. We demonstrate the efficient ablation with average surface roughness S_a values in the frame of [16 nm - 86 nm] without any post-processing.

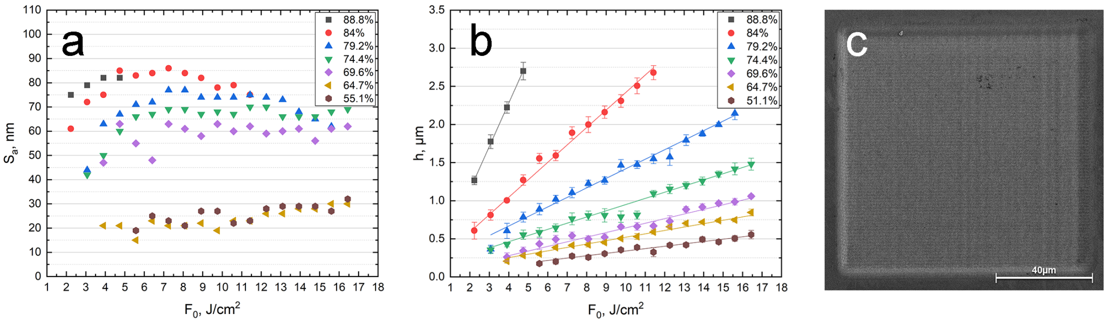

Fig. 1. Results of uGaN ablation using femtosecond UV pulses: (a) experimental data of average surface roughness of ablated areas as a function of pulse energy fluence, (b) experimental data of ablation depth as a function of pulse energy fluence, (c) SEM image of laser ablated area (PO = 79,2 %, F_0 = 15,6 J/cm^2, S_a = 62 nm).

[1] L.K. Nolasco, G.F.B. Almeida, T. Voss, C.R. Mendonça, Femtosecond laser micromachining of GaN using different wavelengths from near-infrared to ultraviolet, J. Alloys Compd. 877, 160259 (2021).

[2] S. Nakamura, T. Mukai, and M. Senoh, Candela-class high-brightness InGaN/AlGaN double-heterostructure blue-light-emitting diodes, Appl. Phys. Lett. 64 (13), 1687–1689 (1994).

[3] H. W. Huang, C. C. Kao, J. T. Chu, H. C. Kuo, S. C. Wang and C. C. Yu, Improvement of InGaN-GaN light-emitting diode performance with a nano-roughened p-GaN surface, IEEE Photon. Technol. Lett. 17(5), 983-985 (2005).

[4] J. Bonse, A. Rosenfeld, and J. Krüger, Implications of transient changes of optical and surface properties of solids during femtosecond laser pulse irradiation to the formation of laser-induced periodic surface structures, Appl. Surf. Sci. 257(12), 5420-5423 (2011).

[5] T Kim, H.S Kim, M Hetterich, D Jones, J.M Girkin, E Bente, and M.D Dawson, Femtosecond laser machining of gallium nitride, MSEB 82(1–3), 262-264 (2001).

[6] Yu-Tang Dai, Gang Xu, and Xin-Lin Tong, Deep UV laser etching of GaN epilayers grown on sapphire substrate, J. Mater. Process. Technol. 212(2), 492-496 (2012).